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MANUFACTURING AND LABORATORY TESTS TO PRODUCE AN IMPROVED COTTON AIRPLANE FABRIC.

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INTRODUCTION.

Improvement of the airplane has been due chiefly to its use in warfare. It is said that the first nation to utilize the airplane in this way was the United States, in its trouble with Mexico in 1911, when a single machine was used for scouting purposes. It remained for the demands of the World War to give the needed impetus to the rapid development of aircraft.

In April, 1917, this country entered the World War. By that time it was apparent that the nation which maintained the superior air force, both in number and efficiency, had a distinct advantage. An immense aerial fleet was believed generally to be the most effective method of exerting immediate pressure on the enemy. This opinion caused Congress to appropriate $640,000,000 for the use of the Signal Corps in developing an adequate airplane service.

The increased production of airplanes, not only by this country but also by the other nations involved in the war, had, naturally,

caused a tremendous drain on material resources, especially upon the supplies of flax and linen, for until January, 1917, nothing but linen had been successfully used for airplane wing covering. The United States was almost entirely dependent upon foreign countries for its linen airplane fabric, because our linen factories were making much heavier fabrics and labor conditions here precluded the economical raising of flax for fiber. As a result of the partial failure of the Canadian flax crop of 1916, the control of the Russian flax and linen stocks by a foreign syndicate, and finally the German capture of Riga, which is the export point for Russian flax, the shortage of linen became acute, especially for the United States, as the allies required all of their available supplies for their own airplanes.

As from 75 to 200 square yards of cloth are necessary to cover a set of airplane wings, the manufacture of several million yards of cloth was required to construct the 22,000 machines provided in the airplane appropriation act of 1917. Consequently, it was found necessary to find a substitute for linen, and as the American Egyptian, Sea Island, and Sakellaridis Egyptian cottons seemed the most desirable substitutes available, the United States naturally turned to that source to relieve the situation.

Within 60 days after the actual beginning of the work a satisfactory cotton substitute had been developed and a million yards had been accepted by the War Department. It is understood that before the armistice was signed all the principal allies had used the cotton fabric and some had used it extensively.

SIGNAL CORPS SPECIFICATIONS FOR AIRPLANE CLOTH.

Gen. George O. Squier, Chief of the Signal Corps of the United States Army, gives the following qualifications for an airplane fabric:

1. It must not weigh more than 5 ounces to the square yard.
2. It must resist flame.
3. It must resist salt water, moist or dry weather, and sudden changes of temperature.
4. It should not stretch in any direction, as the ability to retain its original form is very important.
5. It should have a tensile strength of 75 pounds per inch width in any direction.
6. It should not tear or split because of holes in it.
7. It should shrink the proper amount when the cellulose solution is applied.

In September, 1917, the Signal Corps of the War Department suggested cooperation between the Textile Department of the Bureau of Standards and the Department of Agriculture in developing plans for experiments on cotton airplane fabrics.

At a conference of representatives from these departments a plan for such cooperation was outlined,[1] under which it was agreed that the Bureau of Plant Industry should give assistance in the choice of raw cotton, that the Bureau of Markets, through its technical staff, should be responsible for the manufacturing processes in these investigations, and that the Bureau of Standards should test the finished fabrics.

Preliminary to the tests on different cotton fabrics numerous experimental cloths had been made by the Bureau of Standards in the effort to duplicate the qualities possessed by linen airplane fabrics. Some were made of silk, some of ramie, and some of cotton; others were made with various combinations of these fibers. These fabrics had been given actual flying tests on airplanes at Newport News, Va., and the results indicated that long-staple cotton might be used as the best available substitute for linen in the manufacture of airplane fabric.

As a result of these preliminary tests, the following specifications were drawn for the guidance of manufacturers in producing an airplane fabric:

Specification No. 16,004–A.

SIGNAL CORPS, UNITED STATES ARMY.

Specification for Mercerized Cotton Airplane Fabric (Grade A).

December 15, 1917. Supersedes Specification No. 16,004.

GENERAL:

1. This specification is drawn to cover the requirements of the Signal Corps for all purchases of mercerized cotton airplane fabric, grade A.

MATERIAL:

2. The warp and filling yarns used in the manufacture of this fabric must be size 2/60, according to the English cotton yarn numbers. A tolerance of plus or minus four (± 4) will be allowed in the size of single yarns.

3. The length of the staple of the fabric must be not less than one and one half (1½) inches.[2]

MANUFACTURE:

4. The yarn shall be combed (single or double) and shall be mercerized under tension.

5. It is recommended that the single yarn be given 28 to 34 turns per inch of twist and that 16 turns per inch be used for twisting these yarns together. This procedure may be altered provided that the fabric conforms to this sepcification in other respects.

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[1] The first conference was held in September, 1917, at the office of Dr. S. W. Stratton, Director of the Bureau of Standards, and was attended by the following: Capt. Albert Tilt, of the Signal Corps, then in charge of the development and production of airplane fabrics; Mr. E. D. Walen, in charge of textile work at the Bureau of Standards; Mr. C. S. Scofield, agriculturist in charge of Western Irrigation Agriculture of the Bureau of Plant Industry; and Mr. Fred Taylor, cotton technologist of the Bureau of Markets. Capt. Tilt was succeeded shortly afterwards by Capt. W. H. Thurston, of the Bureau of Aircraft Production, who contributed very materially to the work herein recorded.

[2] This paragraph refers to the length of staple of the cotton to be used in making the fabric.

6. There must be at least 80 threads and not more than 84 threads per inch in both warp and filling.

7. The weave shall be a plain weave.

8. The fabric must be uniform in structure and free from manufacturing imperfections.

9. The fabric under normal moisture conditions must weigh not more than 4.5 ounces per square yard.

10. The width must be 36 inches.

SELECTION OF TEST SPECIMENS:

11. Samples for tests shall be taken from at least five (5) bolts in each warp woven.

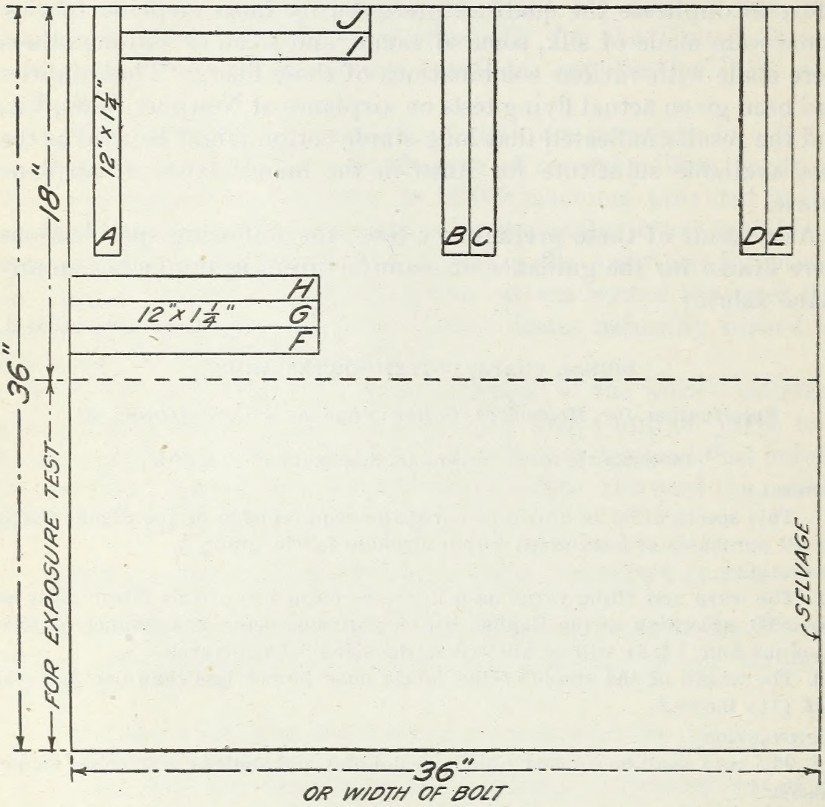

FIG. 1.—Sketch showing the location of the 10 test specimens (lettered A to J) to be cut from the sample.

12. The sample taken from a bolt shall be one (1) yard long and the full width of the bolt; it shall be cut from the fabric at a point ten (10) yards from the end of the bolt.

13. Test specimens for tensile tests, 12 inches long and 1¼ inches wide, shall be cut from each sample taken as shown in figure 1. Threads shall be pulled out from the sides of the test specimens until a width of one (1) inch of woven fabric remains.

Specification No. 16.00¼–A.

TESTS:

14. Tensile test. The tensile test specimens, prepared in accordance with paragraphs 11, 12, and 13, shall be exposed for at least two (2) hours in an

atmosphere of 65 per cent relative humidity at 70° F. (21° C.) and then tested in this atmosphere.

15. The distance between the jaws or clamps of the testing machine at the beginning of the test shall be eight (8) inches (20 cm.). The pulling jaw shall move at the rate of twelve (12) inches per minute during the test.

16. The average breaking load of the five (5) specimens cut in the direction of the warp and the average breaking load of the five (5) specimens cut in the direction of the filling, as shown in figure 1, must each be at least 80 lbs.

17. The elongation shall be observed when the sepcimens are subjected to each of the loads given in Table 1.

18. Whenever practicable an autographic record shall be taken.

19. The elongation must not exceed the values given in Table 1 by more than ten (10) per cent.

20. The average results for both warp and filling shall be reported separately.

Table 1.

Tension in pounds.	Elongation in inches.	
	Warp.	Filling.
10	0.65	0.32
20	.80	.40
70	1.20	.64

21. Test for sizing. Tests for sizing shall be conducted as follows:

(*a*) Dry samples weighing approximately 0.18 oz. (5 gm.) in tared weighing bottles at 221 to 230° F. (105 to 110° C.) to constant weight.

(*b*) Boil the samples in water for ten (10) minutes and rinse thoroughly.

(*c*) Digest each sample in a solution containing 15 cc. commercial diastofor in 500 cc. water at 140° F. (60° C.) for two (2) hours.

(*d*) Wash thoroughly in hot water and then boil for one (1) hour in 500 cc. distilled water and wash again.

(*e*) Dry in tared weighing bottles to constant weight.

(*f*) Percentage sizing $= \frac{\text{loss in weight}}{\text{original weight}} \times 100.$

22. The fabric must not contain more than 3.5 per cent of sizing, as determined by the above method.

23. Mercerization test. Take approximately one-fourth ($\frac{1}{4}$) square foot of the cloth, immerse in boiling distilled water, and stir occasionally while cooling. At the end of ten (10) minutes place a strip of blue and a strip of red litmus paper into the liquid with the fabric and allow them to remain five (5) minutes. At the end of this time the litmus papers must have retained their original colors. Any cloth showing either an acid or alkaline reaction shall be rejected. This test may be made on the yarn before weaving by substituting a small handful of the yarn for the cloth sample.

INSPECTION AND REJECTION:

24. The Signal Corps inspector shall mark all accepted material close to the end of each bolt with the official acceptance stamp. Rejected material shall be marked with the rejection stamp and shall not be resubmitted without the express consent of the Signal Corps. The acceptance and rejection stamps shall

be so placed that they do not injure the material, or, in the case of rejected fabric, so that the marking does not preclude the use of the material for other than Government work.

25. The inspector shall at all times have free access to all parts of the mills which concern the manufacture of fabric ordered to this specification, and shall be afforded every facility to satisfy himself that the fabric is in accordance with this specification.

REPLACEMENTS:

26. All fabric that does not conform to this specification shall be rejected and shall be replaced by the manufacturer at his expense.

Communications regarding all technical matters pertaining to specifications should be addressed to the Specification Section, Signal Corps, U. S. Army, Washington, D. C.

GEORGE O. SQUIER,
Major General, Chief Signal Officer.

Specification No. 16,005–A.

SIGNAL CORPS, UNITED STATES ARMY.

Specifications for mercerized cotton airplane fabric (grade B).

December 15, 1917. Supersedes Specification No. 16,005.

[These specifications are the same as the 2/60 (Spec. No. 16,004–A) except for changes in the following numbers: 1, 2, 5, 6, 9, 16, and 17.]

1. This specification is drawn to cover the requirements of the Signal Corps for all purchases of mercerized cotton airplane fabrics, Grade B.

2. The warp and filling yarns used in the manufacture of this fabric must be size 3/80, according to the English cotton-yarn numbers. A tolerance of plus or minus four (±4) will be allowed in the size of single yarns.

5. It is recommended that the single yarn be given 36 to 40 turns per inch of twist and that 18 to 20 turns per inch be used for twisting these yarns together. This procedure may be altered provided that the fabric conforms to this specification in other respects.

6. There must be at least 68 threads and not more than 72 threads per inch in both warp and filling.

9. The fabric, under normal moisture conditions, must not weigh more than four (4) ounces per square yard.

16. The average breaking load of the five (5) specimens, cut in the direction of the warp and the average breaking load of the five (5) specimens cut in the direction of the filling, as shown in figure 1, must each be at least 73 pounds.

17. The elongation shall be observed when the specimens are subjected to each of the loads given in Table 1.

Tension in pounds.	Elongation in inches.	
	Warp.	Filling.
10	0.70	0.44
20	.86	.52
65	1.16	.78

MILL TESTS.

It was to improve upon the quality of the fabric produced by using the above specifications as guides and to determine the most suitable cotton for airplane purposes that the Bureau of Markets made the tests herein described. Inspection trips were made to various airplane factories by experts of the Bureau of Markets and the Bureau of Standards to obtain first-hand information as to the requirements of airplane fabrics.

VARIETIES OF COTTON TESTED.

Meanwhile representatives of the Bureau of Markets selected for the manufacturing tests [3] 5 bales of American Egyptian cotton of the Pima variety No. 1 or fancy in grade, $1\frac{5}{8}$-inch staple; 5 bales of Sea Island cotton of $1\frac{7}{16}$-inch staple—1 bale No. 1 or fancy, 2 bales No. 2 or extra choice, and 2 bales No. 3 or choice, in grade; and 4 bales of Sakellaridis Egyptian cotton—2 bales of high grade and 2 bales of a lower grade, $1\frac{7}{16}$-inch staple.

These tests were made with the view of obtaining immediate results that could be made available during the war, consequently complete tests on all three varieties of cotton were not attempted, such tests only being made as appeared to promise immediate and important results.

MECHANICAL CONDITIONS AT THE MILL.

Throughout the tests, particular care was taken to keep the different lots separate each from the other and to prevent any mixture of the experimental stock with the mill stock. Certain machines were assigned to the testing force, and these machines were used in all the tests so that no mechanical differences could affect the final results. The organization, speeds, and settings used remained practically constant throughout these tests, except for slight changes in the roll settings in the various machines made necessary by the length of staple of the American Egyptian cotton, which was one-eighth inch longer than that of the other cottons. A readjustment of the comber settings was made in order to equalize the amount of waste discarded from the American-Egyptian, Sea Island, and the high grade Sakel-

[3] These tests were conducted at mills in New Bedford, Mass., through the courtesy of Mr. William Whitman, president of the mills. All possible assistance was given to facilitate the work by Mr. J. L. Burton, agent; Mr. J. T. Kirk, superintendent; and Mr. Nield, assistant superintendent of the mills, and the splendid cooperation which was given is acknowledged and appreciated. The actual tests were conducted by Messrs. W. S. Dean, C. E. Coburn, G. H. Anderson, R. V. Hellams, C. E. Killingsworth, and H. B. Richardson, under the general direction of Mr. Fred Taylor, of the Bureau of Markets, Department of Agriculture.

laridis Egyptian cottons. The organization and speeds are given in Table 1 and the settings in Table 2.

TABLE 1. —*Organization and speeds used in the production of 80's yarn.*

	Doubling.	Weight or size.	Draft.	Speeds.
Breaker lap		13.6 ounces		
Finisher lap	4	10.3 ounces	5.2	65 blows per inch.
Beater				1,075 r.p.m.
Card sliver	1	37.0 grains	122.0	
Cylinder				165 r.p.m.
Licker-in				425 r.p.m.
Doffer				6 r.p.m.
Sliver lap	24	425.0 grains	2.09	
Ribbon lap	4	395.0 grains	4.3	
Comber (8 heads)	8	43.0 grains	73.5	
20 per cent waste.				
First drawing	6	48.0 grains	5.3	315 r.p.m. front roll.
				145 r.p.m. cal. roll.
Second drawing	6	50.0 grains	5.8	315 r.p.m. front roll.
				145 r.p.m. cal. roll.
Slubber	1	0.52 H. R	3.12	220 r.p.m. front roll.
				537 r.p.m. spindle.
Intermediate	2	1.40 H. R	5.4	225 r.p.m. front roll.
				790 r.p.m. spindle.
Fine frame	2	4.25 H. R	6.1	178 r.p.m. front roll.
				1,120 r.p.m. spindle.
Jack frame	2	16.00 H. R	7.5	98 r.p.m. front roll.
				1,480 r.p.m. spindle.
Spinning (ring)	2	80's	10	82 r.p.m. front roll.
				9,200 r.p.m. spindle.

TABLE 2.—*Settings used in the production of 80's yarn made from American Egyptian cotton, 1⅝ inch staple.*

Machine.	Setting.	Inches.	Inches.	Inches.
Pickers:				
Breaker	Feed roll to beater	5/16		
	Grids from beater, top	7/16		
	Grids from beater, bottom	½		
Finisher	Feed roll to beater	5/16		
	Grids from beater, top	⅜		
	Grids from beater, bottom	½		
Cards			Center	
	Feed plate to licker-in	0.010		
	Mote knives	0.012 top		0.010 bottom.
	Licker-in to cylinder	0.007		
	Back plate to cylinder	0.027 top		0.034 bottom.
	Flats to cylinder	0.009 back	0.008	0.007 front.
	Front plate to cylinder	0.034 top		0.034 bottom.
	Doffer to cylinder	0.007		
	Doffer comb to doffer	0.012		
	Licker-in screen	0.250 front		0.010 back.
	Cylinder screen	0.010 back	0.034	0.250 front.
	Center to center of rolls	First to second roll	Second to third roll.	Third to fourth roll.
Sliver lap		2¼	2½	
Ribbon lap		1 5/16	2	2.
First drawing		1⅜	1⅞	1 13/16.
Second drawing		1⅜	1⅞	1 13/16.
Slubber		1¾	1¾	
Intermediate		1¾	1¾	
Fine frame		1 13/16	1 13/16	
Jack		1 13/16	1⅞	
Spinning (ring)	Center to center of rolls, top.	1⅝	1¼[1]	
	Center to center of rolls, bottom.	1 7/16	1¼	

[1] Owing to the length of staple being spun, it was necessary to release the weight on the middle roll.

PERCENTAGE OF WASTE.

Weighings of stock and waste were made at the different machines from the pickers through the combers, and from these data the percentages of waste discarded during each process were found, as shown in Table 3.

TABLE 3.—*Waste percentages of American Egyptian, Sea Island, and Sakellaridis Egyptian cotton.*

Kind of cotton	Pima A. E.	Sea Island.	Sakellaridis Egyptian.	
Grade	Fancy or No. 1.	1 B/C No. 1 or fancy. 2 B/C No. 2 or extra choice. 2 B/C No. 3 or choice.	High grade.	Lower grade.
Length of staple	1⅜ inches.	1 7/16 inches.	1 7/16 inches.	1 7/16 inches.
PICKERS.				
Opener-breaker: [1]				
Visible	1.16	2.17	1.17	1.73
Invisible	1.17	.87	1.30	1.38
Total visible and invisible	2.33	3.04	2.47	3.11
Finisher: [1]				
Visible	.48	.65	.55	1.06
Invisible	.77	.89	.98	1.26
Total visible and invisible	1.25	1.54	1.53	2.32
Through pickers: [2]				
Visible	1.63	2.80	1.71	2.76
Invisible	1.92	1.73	2.25	2.60
Total visible and invisible	3.55	4.53	3.96	5.36
CARDS.[1]				
Flat strippings	4.41	4.13	4.19	4.62
Cylinder and doffer strippings	.86	.85	.75	.87
Motes and fly	1.29	1.25	1.25	2.12
Sweepings	.17	.24	.16	.23
Total visible	6.73	6.47	6.35	7.84
Invisible	.30	Gain .47	Gain .50	0.00
Total visible and invisible	7.03	6.00	5.85	7.84
Pickers and cards: [2]				
Visible	8.12	8.98	7.81	10.18
Invisible	2.20	1.28	1.77	2.60
Total visible and invisible	10.32	10.26	9.58	12.78
COMBER.[1]				
Visible	20.56	19.27	20.11	23.32
Invisible	.34	Gain .95	Gain .76	Gain .08
Total visible and invisible	20.90	18.32	19.35	23.24
Pickers, cards, and combers: [2]				
Visible	26.59	26.27	25.99	30.52
Invisible	2.50	.43	1.08	2.53
Total visible and invisible	29.09	26.70	27.07	33.05

[1] Percentages based on the net weights fed to the respective machines.
[2] Percentages based on the net weights fed to the opener.

COMPARATIVE STRENGTH AND STRESS TESTS OF YARNS AND FABRICS.

The cotton shown in the waste table was spun into 3/80's and 2/60's yarns, which were mercerized and woven into cloth similar to that produced by the mill, according to the specifications of the Signal Corps. Tests of the strength and stretch were made in compliance with specifications given above, with the results shown in the tables which follow. The results on breaking strength for both gray and mercerized yarns are shown in Table 4.

TABLE 4.—*Breaking strength of 80's, 3/80's, 60's, and 2/60's gray and mercerized yarns.*

[Twist multiple of 4 used in single and ply yarn.]

	80's gray.	3/80's gray.	3/80's mercerized.	60's gray.	2/60's gray.	2/60's mercerized.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
American Egyptian No. 1 (fancy)	[1] 28.2	142.4	138.1	47.9	118.5	126.3
Sakellaridis high grade	30.6	153.1	163.5	49.5	131.1	141.6
Sakellaridis lower grade	28.3	144.7	148.0	46.2	124.8	136.7
Sea Island, 1 bale No. 1 (fancy), 2 bales No. 2 (extra choice), 2 bales No. 3 (choice)	25.7	137.0	138.0	43.8	112.1	123.7

[1] The figures in this table have been corrected for slight variations in the weight of the yarn.

It will be noticed from Table 4 that the Sakellaridis cotton showed greater strength than either the American Egyptian or the Sea Island cotton. In the 3/80's mercerized yarn, the breaking strength of the high-grade Sakellaridis was 18.4 per cent greater than that of either the American Egyptian or the Sea Island, the latter two being equal in strength. In the 2/60's mercerized yarn, the breaking strength of the high-grade Sakellaridis was 12.1 per cent greater than that of the American Egyptian and 14.4 per cent greater than that of the Sea Island.

The tests on the cloth, results of which are shown in Tables 5 and 6, indicated that the strength of the yarns was reflected in the cloth, confirming the results previously obtained on the yarns.

TABLE 5.—*Weight, breaking strength, and stretch of 3/80's, 68 by 68, plain-weave fabric made from mercerized yarn. (Twist multiple of 4 used in the single and ply yarn.)*

3/80's.	Ounce per square yard.	Strength in pounds.		Stretch in inches at different loads.					
				Warp.			Filling.		
		Warp.	Filling.	10 pounds.	20 pounds.	65 pounds.	10 pounds.	20 pounds.	65 pounds.
American Egyptian	3.90	75	84	0.24	0.36	0.67	0.24	0.36	0.66
Sakellaridis high grade	3.91	86	90	.37	.50	.78	.15	.22	.43
Sakellaridis lower grade	4.00	83	89	.37	.53	.84	.20	.28	.55
Sea Island	4.00	78	89	.39	.56	.88	.20	.30	.56

TABLE 6.—*Weight, breaking strength, and stretch of 2/60's, 80 by 80, plain-weave fabric made from mercerized yarn. (Twist multiple of 4 used in the single and ply yarn.)*

2/60's.	Ounce per square yard.	Strength in pounds.		Stretch in inches at different loads.					
				Warp.			Filling.		
		Warp.	Filling.	10 pounds.	20 pounds.	70 pounds.	10 pounds.	20 pounds.	70 pounds.
American Egyptian	4.23	87	89	0.53	0.75	1.20	0.19	0.30	0.62
Sakellaridis high grade	4.15	98	100	.32	.49	.83	.20	.27	.50
Sakellaridis lower grade	4.22	90	99	.40	.61	1.00	.18	.27	.51
Sea Island	4.00	85	91	.48	.66	1.03	.19	.29	.54

By comparing the combined strengths of the warp and filling as given in Tables 5 and 6, it was found that in the 3/80's cloth the breaking strength of the high-grade Sakellaridis was 10.7 per cent greater than that of the American Egyptian and 5.4 per cent greater than that of the Sea Island. However, in the 2/60's fabric the breaking strength of the high-grade Sakellaridis was 12.5 per cent greater than that of either the American Egyptian or the Sea Island, the latter two, as in the case of the yarns, being equal in strength.

The results of the tests as to stretch as shown by Tables 5 and 6 are not conclusive.

VARIATION OF TWIST.

Having compared the three varieties in regard to strength and stretch, using the mill's twist multiple of four, the effect of varying the twist in the single and three-ply yarns was investigated. Single 80's were spun from the American Egyptian cotton with twist multiples[1] varying from 3.39 to 4.27. In plying a part of the 80's yarn the same multiple was used as had been used in spinning the corresponding single yarn. The remaining 80's yarn was plied to give approximately two turns more or less twist than this basis, thus producing 3/80's yarns of different twists from which selections could be made. After carefully determining the size and tensile strength of the yarns made with each different twist multiple, the strongest ply yarn was found to result from a combination of 3.83 twist multiple in the singles with 3.63 in plying. The results of these tests are shown in Table 7.

[1] A twist multiple is an arbitrary number by which the square root of the hank or size of the yarn is multiplied. The product thus obtained shows the twist per inch in the resulting yarn.

TABLE 7.—*Effect of twist on 80's singles and 3/80's yarn made from the American Egyptian cotton.*

BREAKING STRENGTH IN POUNDS PER SKEIN.

80's single yarn.			3/80's yarn.			
Twist multiple.	Twist per inch.	Breakings per skein.	1 to 2 turns more than basis.	Same twist multiple as single yarn (basis).	1 to 2 turns less than basis.	2 to 3 turns less than basis.
4.27	37.66	28.1	142.1	141.7	145.0	.....
4.15	36.61	28.7	143.8	143.8	145.4	.....
4.03	35.62	28.2	138.1	142.2	138.8	.....
3.93	34.61	29.5	145.1	144.5	145.1	.....
3.83	33.80	29.1	147.6	147.2	149.8	149.6
3.73	32.95	29.5	143.0	146.0	145.0	.....
3.63	32.15	29.7	141.3	141.2	142.2	.....
3.55	31.38	30.5	143.8	146.0	142.1	.....
3.39	29.95	30.2	142.9	145.3	142.4	.....

The twist test was carried one step further. A fabric was woven from a warp having a twist multiple of four and a filling having the varying twist multiples shown in Table 7. The resulting cloths were tested for strength and stretch in the direction of the filling, and it was found that the twist as recommended in the specifications of the Signal Corps was excessive. The cloth tests in general confirmed the yarn tests, although it appeared that the 3.55 twist multiple for plying, when such yarn was woven, produced the strongest cloth. The results of these tests are shown in Table 8.

TABLE 8.—*Effect of the various twists as related to the breaking strength of 3/80's plain cloth made from American Egyptian cotton, using 4.03 twist multiple in the warp, and twists as indicated in the filling. (Broken in direction of filling.)*

Twist multiple of single and ply yarns (basis).	Strength of fabric in pounds.			Stretch in inches at 65 pounds.		
	1 to 2 turns more than basis.	Basic twist.	1 to 2 turns less than basis.	1 to 2 turns more than basis.	Basic twist.	1 to 2 turns less than basis.
4.27	84.6	79.8	78.0	0.70	1.00	0.73
4.15	84.1	78.2	83.6	.83	.75	.83
4.03	79.0	80.8	82.4	.78	.68	.68
3.93	80.8	80.8	79.2	.73	.70	.73
[1] 3.83	81.8	77.6	82.0	.75	.75	.75
3.73	83.4	80.2	85.2	.73	.70	.68
3.63	85.0	81.2	83.0	.73	.68	.65
3.55	85.0	87.0	87.0	.75	.75	.68
3.39	79.0	87.6	83.0	.70	.75	.70

[1] Another fabric was made with twist multiple giving 2 to 3 turns less per inch than basis, breaking at 77.6 pounds and having a stretch of 0.70 inch at 65 pounds.

Subsequently a cloth was woven from yarn with the twist giving the greatest strength (3.83 twist multiple in the single yarn and 3.63 twist multiple in the ply) both in the warp and filling to determine whether the warp yarn of this softer twist could withstand the chafing

action of the loom and still show a breaking strength comparable to that of the filling alone. Some of this cloth was made in the gray, some was made from yarn mercerized under tension, and some was woven in the gray and later mercerized in the piece. The results of strength and stretch tests on these fabrics are shown in Table 10, and further corroborated the results found in the previous test.

VARIATION OF WEAVE.

Although the plain weave was generally considered the most desirable for airplane fabrics because of its simplicity of manufacture, tests were made to determine the adaptability of other weaves, such as the 2/2 twill and the 2/2 basket weave. These results are shown in Table 9.

TABLE 9.—*Comparison of different weaves in cloths made from American Egyptian cotton.*

Weave.		Twist per inch.		Oz. per sq. yd.	Breaking strength.		Stretch in inches at different loads.					
							Warp.			Filling.		
		Single.	Ply.		Warp	Fill.	10 lbs.	20 lbs.	65 lbs.	10 lbs.	20 lbs.	65 lbs.
Plain, 68 by 68	3/80	35.62	20.6	3.90	75	84	0.24	0.36	0.67	0.24	0.36	0.66
Plain, 76 by 76	3/90	35.62	19.0	4.06	85	82	.49	.65	1.00	.15	.24	.53
Plain, 80 by 80	2/60	30.5	21.5	4.23	87	89	.53	.75	[1] 1.20	.19	.30	[1] .62
2/2 twill, 68 by 68	3/80	35.62	20.6	3.86	73	82	.11	.19	.49	.16	.26	.63
2/2 basket, 68 by 68	3/80	35.62	20.6	3.75	70	77	.12	.20	.41	.11	.20	.48
2/2 basket, 104 by 108	2/80	33.80	21.5	3.87	76	85	.11	.17	[1] .41	.16	.23	[1] .52

[1] The stretch for the 2-ply cloth was taken at 70 pounds instead of 65 pounds.

Although the above figures indicate that the twill and the basket weaves made from the 3/80's yarn might be substituted for the plain weave because of the small amount of stretch, it is doubtful whether they could be used unless reconstructed to eliminate the tendency to "draw" when applied to the airplane frame. To remedy this tendency a 2/2 basket weave was made, using 2/80's yarn with a construction of 104 by 108, which resulted in a cloth having practically the same strength as the plain cloth but considerably less stretch. The objection to this fabric is that it had to be made out of a finer yarn, which increased the cost to the manufacturer by decreasing the production, there being 108 picks per inch in such fabric against 68 picks in 3/80's fabric and 80 picks in 2/60's fabric. It will be noticed that all of the fabrics, as shown in Table 9, come within the Signal Corps specifications, excepting the 2/2 basket weave of 3/80's yarn, 68 by 68 construction, which broke in the warp direction several pounds under the tensile-strength requirement.

MERCERIZATION.

The Signal Corps specifications, as given on pages 4 to 9, required that the cloth be made from yarn mercerized under tension. This process usually tends to reduce the amount of stretch and at the same time to increase the breaking strength and the doping[4] properties of the finished fabric. The results of the tests on gray and mercerized yarns, from the three varieties of cotton tested, are shown in Table 4. Considerable variation existed between the breaking strengths of yarns before and after mercerization, some gaining about 10 per cent in strength and others losing about 3 per cent. These variations are probably due to difficulties in maintaining constant mechanical and chemical conditions throughout different lots of yarns during the process of mercerization. It should be realized that exact duplication of yarn mercerization is almost impossible.

It was realized that if physical properties of piece mercerized cloth equal to those of cloth made from mercerized yarn, could be obtained, a tremendous amount of time, labor, and money could be saved. With this in mind, a large amount of gray cloth of plain weave was made so as to determine the feasibility of mercerizing in the piece instead of in the yarn. This fabric was then turned over to a finishing plant and mercerized in the piece, after which it was tested and found to have less stretch than fabrics woven from mercerized yarns, and at the same time practically the same strength. In almost all of the yarn-mercerized cloths, the stretch had been greater in the direction of the warp than in the direction of the filling, but in the first piece-mercerized fabric, the reverse was found to be true. Not only was the warp stretch reduced below that of the filling, but it was found that the stretch could be controlled by various methods of finishing. This fabric, which was made from the American Egyptian cotton from 3 80's yarn, weighed 4.06 ounces per square yard before mercerizing and 3.76 ounces per square yard after mercerizing and at this reduced weight had a breaking strength equal to yarn mercerized cloth made from similar yarn and with the same construction, at the same time it showed the marked decrease in stretch already mentioned. A second lot of the same gray cloth was mercerized in the piece by the same firm without direct supervision of the Bureau of Markets so as to determine the accuracy with which the strength in the warp and filling could be controlled. Very satisfactory results were obtained in that practically identical stretch-stress qualities were produced for the warp and filling with the added advantage of having the stretch approximately one-eighth of an inch less than in either the gray or yarn mercerized fabrics. The results of these tests are shown in Table 10.

[4] See page 38 for definition of doping.

TABLE 10.—*Comparative weight, breaking strength in pounds, and stretch in inches of 3/80's 68 by 68 plain weave gray fabrics, fabrics woven from mercerized yarn, and piece mercerized fabrics all made from American Egyptian No. 1 (Fancy) Pima variety 1§-inch staple cotton.*

Finish.	Twist multiple.		Oz. per sq. yd.	Breaking strength.		Stretch in in. at different loads.					
						Warp.			Filling.		
	Single.	Ply.		Warp.	Fill.	10 lbs.	20 lbs.	65 lbs.	10 lbs.	20 lbs.	65 lbs.
Gray fabric	4.03	4.03	3.90	79	86	0.36	0.54	0.95	0.21	0.32	0.66
Yarn mercerized fabric.	4.03	4.03	3.90	75	84	.24	.36	.67	.24	.36	.66
Gray fabric	3.83	3.63	4.06	83	86	.24	.38	.73	.21	.32	.70
Yarn mercerized fabric.	3.83	3.63	3.94	83	83	.26	.41	.70	.18	.33	.67
No. 1 piece mercerized fabric	3.83	3.63	3.76	80	81	.12	.21	.42	.20	.32	.63
No. 2 piece mercerized fabric	3.83	3.63	3.69	80	83	.16	.26	.52	.16	.26	.55

Following the investigation of the properties of 3/80's piece mercerized fabric made from American Egyptian cotton attention was given to producing a Sea Island 2/60's piece mercerized fabric. Up to this time Sea Island cotton had been almost exclusively used to meet the specifications of the Signal Corps for airplane fabrics. A large amount of 2/60's gray cloth was woven and sent to two finishing plants for mercerizing in the piece without direct supervision of the Bureau of Markets, in order to furnish a correct indication of what might be expected of cloth mercerized in the piece under commercial conditions. The results of these tests were highly successful in that the stretch of the warp and filling was considerably reduced and practically equalized and the strength maintained, confirming the results previously obtained for the 3/80's cloth referred to above. Table 11 gives the results of these tests.

TABLE 11.—*Comparative weight, breaking strength in pounds, and stretch in inches of 6/60's 80 by 80 plain weave gray fabrics, fabrics woven from mercerized yarn, and piece mercerized fabrics, all made from Sea Island cotton.*

Finish.	Twist per inch.		Oz. per sq. yd.	Breaking strength.		Stretch in in. at different loads.					
						Warp.			Filling.		
	Single.	Ply.		Warp lbs.	Fill. lbs.	10 lbs.	20 lbs.	70 lbs.	10 lbs.	20 lbs.	70 lbs.
Gray fabric	30.5	21.5	4.26	76	88	0.43	0.64	0.98	0.16	0.24	0.53
Yarn mercerized fabric.	30.5	21.5	4.00	85	87	.40	.53	.92	.1	.24	.48
Yarn mercerized fabric, standard specifications	28.34	16	4.50	80	80	.65	.80	1.20	.32	.40	.64
No. 1 piece mercerized fabric	30.5	21.5	3.95	82	90	.24	.36	.68	.17	.26	.53
No. 2 piece mercerized fabric	30.5	21.5	3.97	82	81	.17	.27	.54	.13	.22	.52

Not only has piece mercerization the advantage over yarn mercerization of equalizing and reducing the stretch in the warp and filling, but it also has the commercial advantages of increased production, decreased cost, uniformity of output, and conservation of labor, material, and transportation.

In respect to increased production, it was ascertained that three representative finishing plants could with but slight changes in equipment produce enough airplane fabric of the desired quality to meet all the requirements of this country during the war. These three plants represent only a very small portion of the entire mercerizing capacity of the country. The cost of piece mercerization would be about 2 cents per yard, while in the case of yarn mercerized fabric the cost of mercerization would be about 10 cents per yard. In the case of piece mercerization economy also results from the elimination of considerable waste caused by extra handling and tangled threads common to the manufacture of yarn mercerized fabrics. Uniformity of results in piece mercerization can easily be maintained because of the small number of men handling the cloth during mercerization and the simplicity of the operations. Labor and transportation problems are also simplified in that the operations of quilling and beaming are eliminated and a return shipment of the mercerized yarn to the mill is unnecessary.

CORROBORATION OF CERTAIN MILL TESTS BY SIGNAL CORPS AND THE BUREAU OF MARKETS.

With the exception of the special weaves and the 2/60's piece mercerized fabric all of the fabrics which had been produced were submitted to the Signal Corps for strength and stretch tests. The results of these tests were given in Tables 12 and 13. These cloths were numbered and the key to the numbers retained by the Bureau of Markets with full description so that the fabrics could be reproduced at any future date.

TABLE 12.—*Results of tests by the Signal Corps and the Bureau of Markets on cotton airplane fabric made from 3/80's yarn.*

Key or sample No.	Construction.	Tested by	Stretch in inches at different loads.						Breaking strength.		Oz. per square yard.
			Warp.			Filling.			Warp, lbs.	Filling, lbs.	
			10 lbs.	20 lbs.	65 lbs.	10 lbs.	20 lbs.	65 lbs.			
1	3/80's 68 by 68 plain weave made from No. 1 (fancy) Pima American Egyptian gray yarn, single twist, 35.6; ply twist, 20.6	M	.36	.54	.95	.21	.32	.66	79	86	3.9
		S.C.	.43	.59	.96	.42	.54	.93	83	87	
2	Same as No. 1, except made from mercerized yarn	M	.24	.36	.67	.24	.36	.66	75	84	3.9
		S.C.	.38	.52	.80	.31	.41	.69	81	82	
8	3/80's 68 by 68 plain weave made from No. 1 (fancy) Pima American Egyptian gray yarn, single twist, 33.8; ply twist, 18.5	M	.24	.38	.73	.21	.32	.70	83	86	4.06
		S.C.	.19	.51	.85	.19	.51	.85	86	88	
9	Same as No. 8, except made from mercerized yarn	M	.26	.41	.70	.18	.33	.67	83	83	3.94
		S.C.	.40	.52	.80	.38	.46	.76	87	86	
11	Same as No. 8 mercerized in the piece and finished with same width as gray cloth	M	.12	.21	.42	.20	.32	.63	80	81	3.76
		S.C.	.25	.33	.59	.31	.40	.74	85	88	
12	Same as No. 11 but starched with ½ per cent corn starch	M	.19	.31	.56	.19	.31	.64	82	82	3.82
		S.C.	.16	.28	.48	.25	.38	.68	81	82	
13	Same as No. 8 but increased 1 inch in width on tentering frame	M	.26	.42	.79	.18	.30	.62	79	91	4.05
		S.C.	.24	.36	.70	.23	.34	.68	84	85	
14	Same as No. 13 but starched with ½ per cent corn starch	M	.26	.43	.80	.19	.35	.71	85	91	3.98
		S.C.	.43	.62	.96	.31	.45	.79	85	96	
23	3/80's 68 by 68 plain weave made from Sea Island mercerized yarn, single twist, 35.6; ply twist, 20.6	M	.39	.56	.88	.20	.30	.56	78	89	4.01
		S.C.	.46	.62	.90	.28	.35	.59	79	87	
30	3/80's 68 by 68 plain weave made from high grade Sakel; mercerized yarn. Single twist, 35.6; ply twist, 20.6	M	.36	.50	.78	.15	.22	.43	86	90	3.91
		S.C.	.50	.66	.93	.21	.31	.50	90	93	
31	3/80's 68 by 68 plain weave made from lower grade Sakel; mercerized yarn, single twist, 35.6; ply twist, 20.6	M	.37	.53	.84	.20	.28	.55	83	89	4.00
		S.C.	.27	.39	.64	.19	.29	.51	84	86	

M=Bureau of Markets; S. C.=Signal Corps. Twist is stated in turns per inch of yarn.

TABLE 13.—*Results of tests by the Signal Corps and the Bureau of Markets on 2/60's cotton airplane fabric.*

Key or sample. No.	Construction.	Tested by—	Stretch in inches at different loads.						Breaking strength.		Oz. per sq. yd.
			Warp.			Filling.			Warp.	Filling.	
			10 lbs.	20 lbs.	70 lbs.	10 lbs.	20 lbs.	70 lbs.			
7	2/60's 80 by 80 plain weave, made from No. 1 (fancy) Pima American Egyptian mercerized yarn. Single twist, 30.5; ply twist, 21.5.	M....	0.53	0.75	1.20	0.19	0.30	0.62	*Lbs.* 87	*Lbs.* 89	4.23
		S. C..	.46	.64	1.04	16	.26	.51	89	88	
21	2/60's 80 by 80 plain weave made from Sea Island mercerized yarn. Single twist, 30.5; ply twist, 21.5.	M....	.48	.66	1.03	.19	.29	.54	85	91	4.0
		S. C..	.52	.73	1.07	.28	.41	.81	88	93	
32	2/60's 80 by 80 plain weave made from high-grade Sakel. mercerized yarn. Single twist, 30.5; ply twist, 21.5.	M....	.32	.49	.83	.20	.27	.50	98	100	4.15
		S. C..	.46	.66	.96	.25	.34	.55	98	97	
33	2/60's 80 by 80 plain weave, made from lower grade Sakel. mercerized yarn. Single twist, 30.5; ply twist, 21.5.	M....	.40	.61	1.00	.18	.27	.51	90	99	4.22
		S. C..	.62	.84	1.19	.21	.30	.50	93	98	

M=Bureau of Markets; S. C.=Signal Corps. Twist is stated in turns per inch of yarn.

Important results obtained by the Signal Corps on the 15 fabrics (see Tables 12 and 13) are shown in several graphs reproduced below. These graphs are copies of those produced by the stretch recording device on the automatic cloth-testing machine of the dead-weight type used in all of the tests by the Signal Corps. The effect of mercerization may readily be seen by a comparison of figures 1 and 2, which relate, respectively, to gray and yarn-mercerized fabrics as represented by key or sample numbers 1 and 2, and of figures 3, 4, and 5, which relate, respectively, to gray, yarn-mercerized, and piece-mercerized fabrics as represented by the key numbers 8, 9, and 11. The stretch figures of the Signal Corps given in Tables 12 and 13 were obtained from the graphs, the point where the graph leaves the vertical line on the left being considered the origin of coordinates. This assumption was followed in all of the Bureau of Markets' tests, as it is obvious that until the line leaves the vertical there is no load sustained. This eliminates inconsistencies due to inserting the sample between the jaws at different degrees of tension or tautness. No comment upon the Signal Corps graphs is necessary other than to state that in general they followed very closely the results obtained in the tests made by the Bureau of Markets. (See Tables 12 and 13 for comparison.) Figures 6, 7, and 8, which relate to fabrics represented by the key numbers 7, 21, and 32, respectively, illustrate the

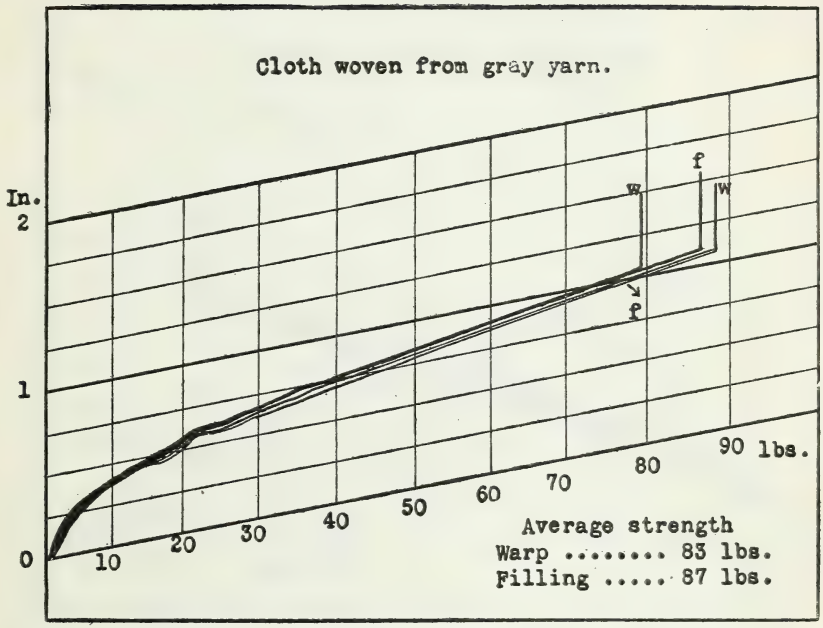

FIG. 1.—Elasticity curves reproduced from those made by the automatic recording device of the cloth-testing machine during the testing of plain-weave cloth made from 3/80's gray yarn spun from American Egyptian cotton of grade No. 1 (fancy), 1§ inches in length of staple.

Twist per inch of singie yarn, 35.62.
Twist per inch of ply yarn, 20.6.
Construction of cloth, 68 ends by 68 picks.

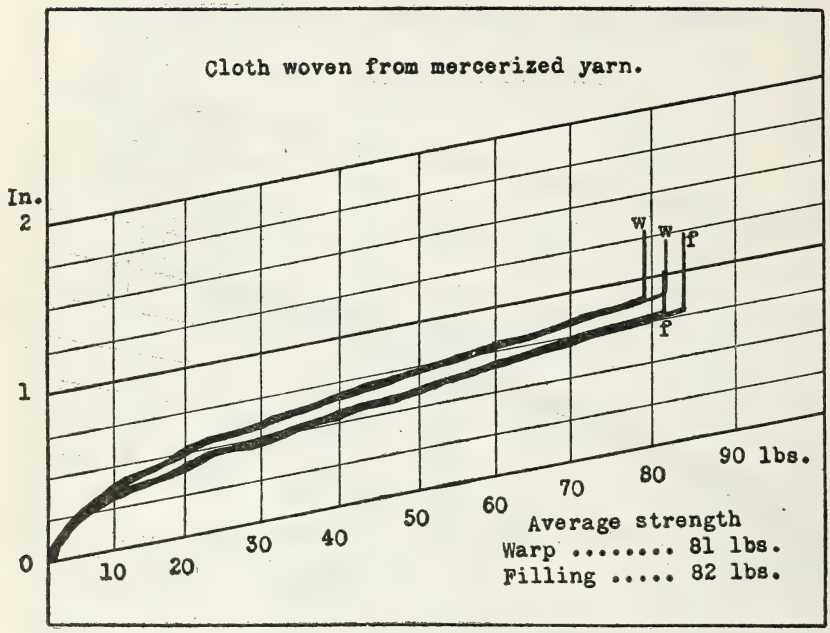

FIG. 2.—Elasticity curves reproduced from those made by the automatic recording device of the cloth-testing machine during the testing of plain-weave cloth made from 3/80's yarn mercerized under tension. Yarn spun from American Egyptian cotton grade of No. 1 (fancy), 1⅝ inches in length of staple.

Twist per inch of single yarn, 35.62.
Twist per inch of ply yarn, 20.6.
Construction of cloth, 68 ends by 68 picks.
Strength of caustic, 64 degrees Twaddle.

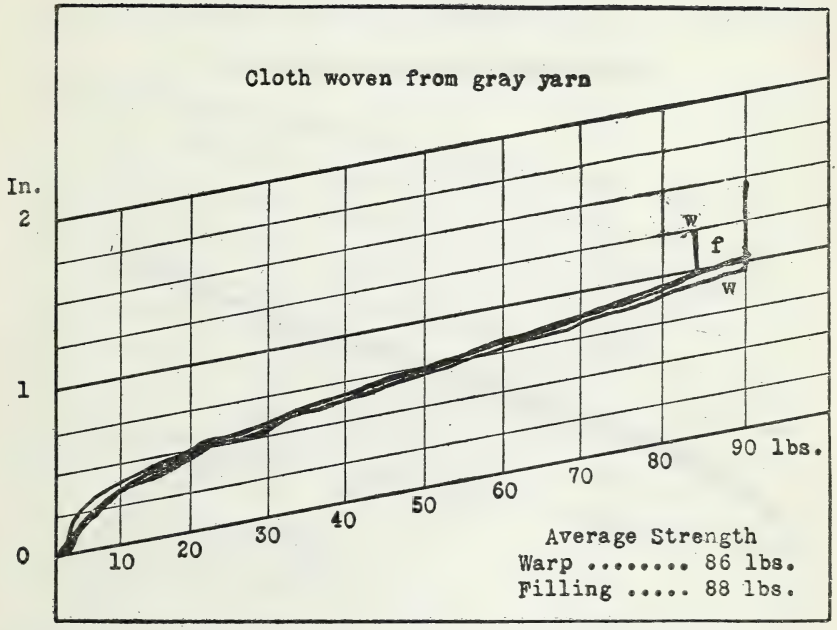

FIG. 3.—Elasticity curves reproduced from those made by the automatic recording device of the cloth-testing machine during the testing of plain-weave cloth made from 3/80's gray yarn spun from American Egyptian cotton of grade No. 1 (fancy), 1⅝ inches in length of staple.

Twist per inch of single yarn, 33.8.
Twist per inch of ply yarn, 18.5.
Construction of cloth, 68 ends by 68 picks.

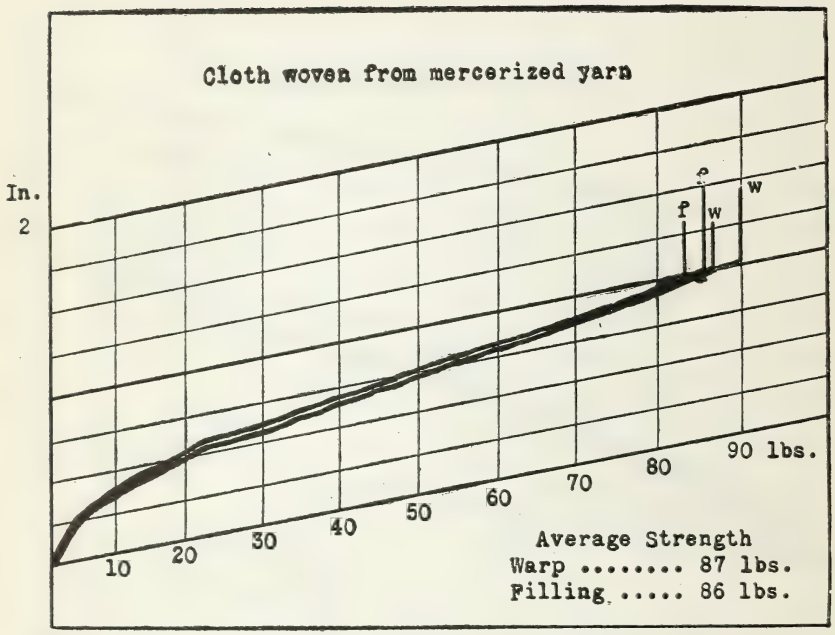

FIG. 4.—Elasticity curves reproduced from those made by the automatic recording device of the cloth-testing machine during the testing of plain-weave cloth made from 3/80's mercerized yarn spun from American Egyptian cotton of grade No. 1 (fancy), 1⅛ inches in length of staple.

Twist per inch of single yarn, 33.8.
Twist per inch of ply yarn, 18.5.
Construction of cloth, 68 ends by 68 picks.
Strength of caustics, 64 degrees Twaddle.

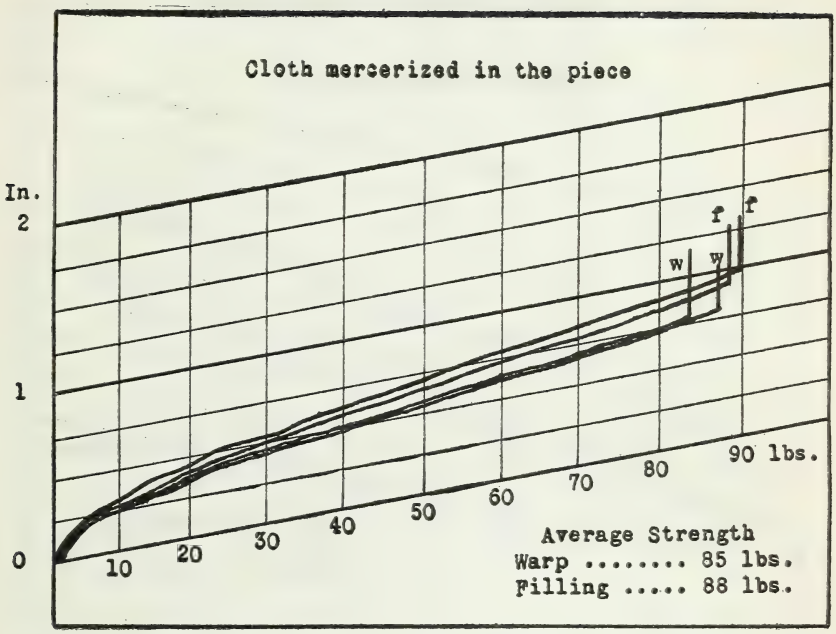

FIG. 5.—Elasticity curves reproduced from those made by the automatic recording device of the cloth-testing machine during the testing of plain-weave cloth mercerized in the piece. Cloth made of 3/80's yarn spun from American Egyptian cotton of grade No. 1 (fancy), 1⅛ inches in length of staple.

Twist per inch of single yarn, 33.8.
Twist per inch of ply yarn, 18.5.
Construction of cloth, 68 ends by 68 picks.
Strength of caustic, 64 degrees Twaddle.

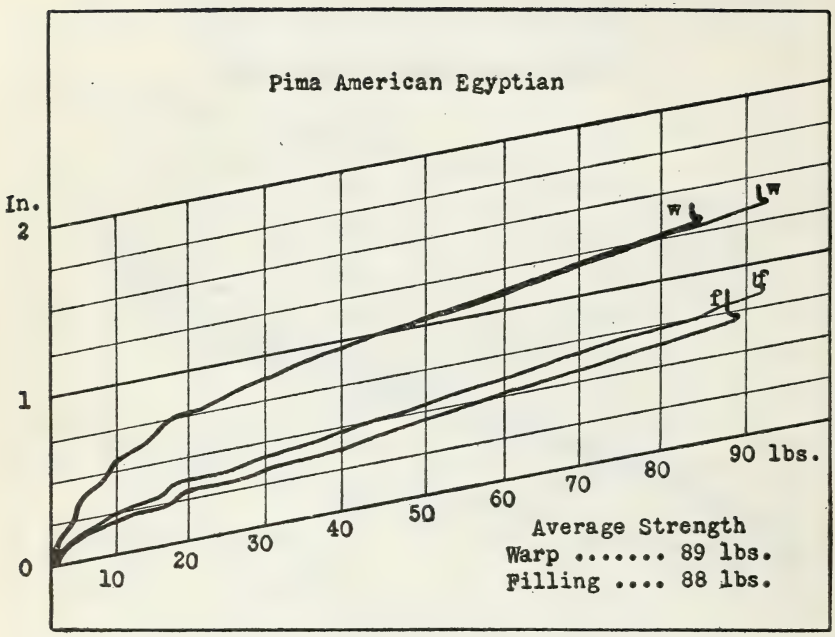

FIG. 6.—Elasticity curves reproduced from those made by the automatic recording device of the cloth-testing machine during the testing of plain-weave cloth made from 2/60's yarns mercerized under tension. Yarn spun from American Egyptian cotton of grade No. 1 (fancy), 1⅝ inches in length of staple.

Twist per inch of single yarn, 30.5.
Twist per inch of ply yarn, 21.5.
Construction of cloth, 80 ends by 80 picks.
Strength of caustic, 64 degree Twaddle.

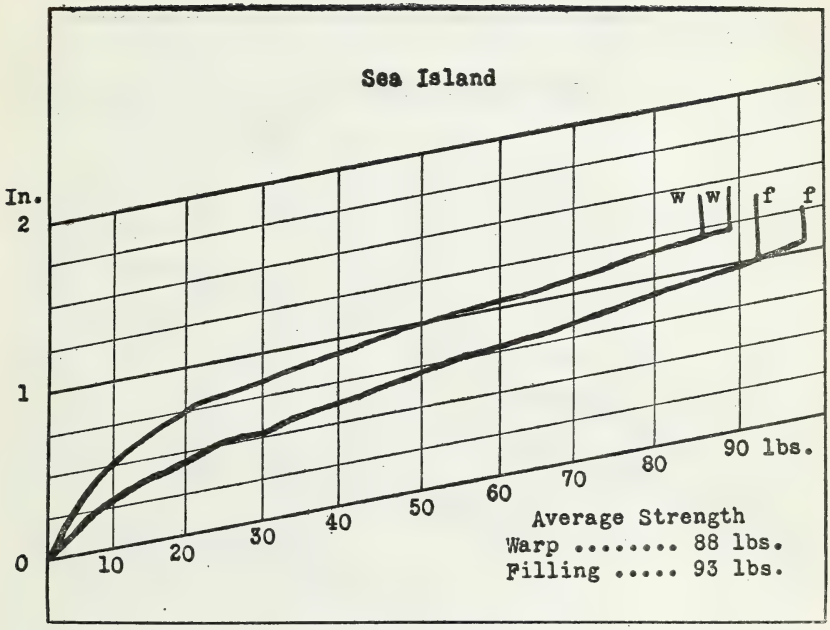

FIG. 7.—Elasticity curves reproduced from those made by the automatic recording device of the cloth-testing machine during the testing of plain-weave cloth made from 2/60's yarns mercerized under tension. Yarn spun from Sea Island cotton of grade represented by a mixture of one bale No. 1, two bales No. 2, and two bales of No. 3, all of $1\frac{7}{16}$ inches in length of staple.

Twist per inch of single yarn, 30.5.
Twist per inch of ply yarn, 21.5.
Construction of cloth, 80 ends by 80 picks.
Strength of caustic, 64 degrees Twaddle.

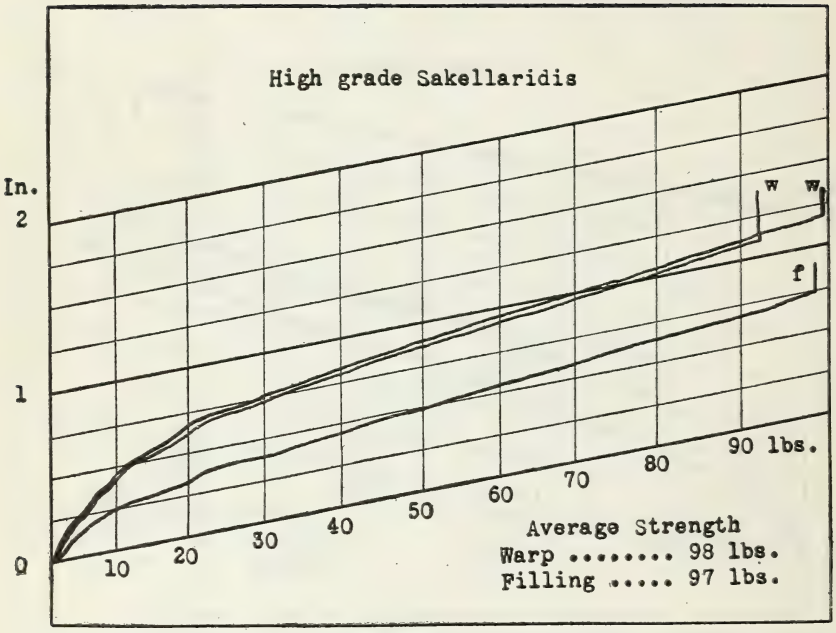

FIG. 8.—Elasticity curves reproduced from those made by the automatic recording device of the cloth-testing machine during the testing of plain-weave cloth made from 2/60's yarns mercerized under tension. Yarn spun from Sakellaridis Egyptian cotton of high grade, $1\frac{7}{16}$ inches in length of staple.

Twist per inch of single yarn, 30.5.
Twist per inch of ply yarn, 21.5.
Construction of cloth, 80 ends by 80 picks.
Strength of caustic, 64 degrees Twaddle.

wide differences between the stretch of the warp and the filling in the 2/60's fabric, and also give a comparison of the fabrics obtained from the three varieties of cotton used. The wide differences between the stretch in the warp and the filling in the 2/60's cloth as compared to the 3/80's cloth is probably due to the greater number of ends and picks per inch in the 2/60's cloth, and also to the number of single threads plied in its manufacture.

LABORATORY TESTS.[5]

Realizing that tests to produce an improved airplane fabric would be incomplete without a consideration of mercerization and "doping" properties, investigations were conducted regarding these properties in the chemical laboratory of the New Bedford Textile School and at several cloth-fininshing plants. These tests consisted of detailed study by laboratory experiments to determine the effect of the various contributing agents to mercerization and doping and the application of these results on a commercial scale. The laboratory tests were conducted on pieces of cloth 8 inches wide by 12 inches long inserted between horizontal jaws of a special cloth-testing machine equipped with a trough in which the various chemicals could be held, thus producing small samples closely resembling those produced under commercial conditions. These samples were tested according to the specifications of the Signal Corps as given on pages 4 to 9 for final results relating to the breaking strength and the stretch. Other tests were made in which the cloth was subjected to continual stresses and microscopic examination.

MERCERIZATION.

To determine the best conditions for mercerization, preliminary tests were conducted to ascertain the strength of the caustic, the tension during the treatment, the temperature of the caustic, the length of treatment, and the effect of additions of other chemicals to the bath. In these tests commercial caustic soda was used, a fresh solution being made from the same lot of dry caustic for each batch mercerized, so as to eliminate any variations in the process. These tests indicated that the best results could be obtained under the following conditions:

(*a*) One hundred four degree Twaddle solution of caustic soda, figure 9.
(*b*) Highest tension possible when neutralizing, figure 10.
(*c*) Highest possible temperature of wash water, figure 11.
(*d*) Time interval of one minute or less before neutralizing, figure 12.
(*e*) No additions of silicate of soda or other chemicals, figure 13.

[5] These tests were conducted by Prof. Everett H. Hinckley, head of the chemical and dyeing department of the New Bedford Textile School, in collaboration with the Bureau of Markets.

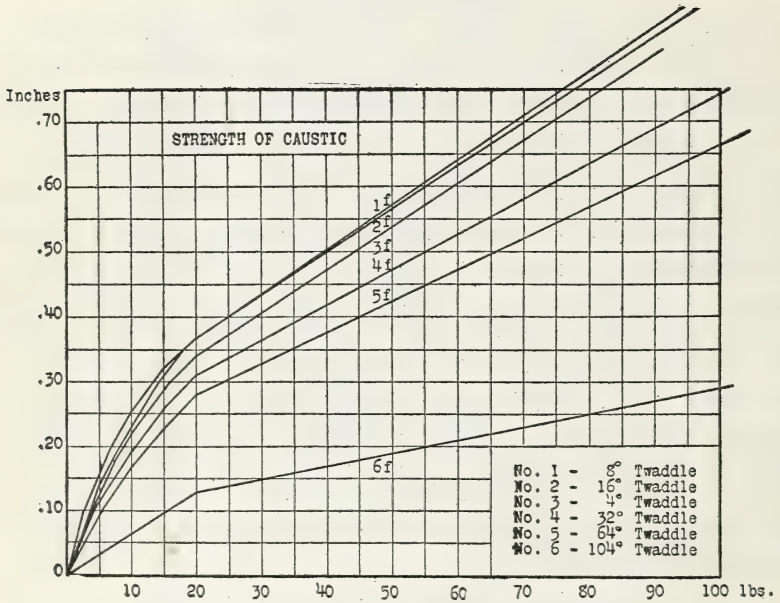

FIG. 9.—Elasticity curves showing the effect of different strengths of caustic on plain weave cloth made from 3/80's gray yarn spun from American Egyptian cotton of grade No. 1 (fancy), 1⅝ inches in length of staple.

Twist per inch of single yarn, 33.8.
Twist per inch of ply yarn, 18.5.
Construction of cloth, 68 ends by 68 picks.

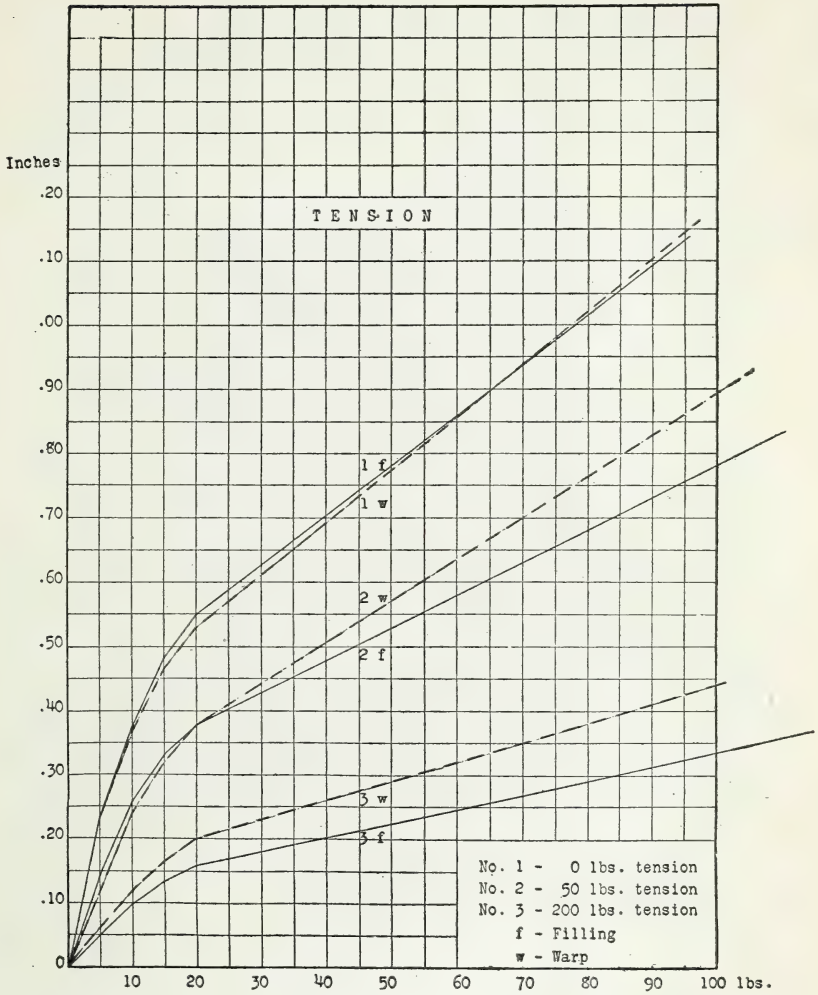

FIG. 10.—Elasticity curves showing the effect of different tensions at which the cloth is held during mercerization. Plain-weave cloth made of 3/80's gray yarn spun from American Egyptian cotton of grade No. 1 (fancy), $1\frac{5}{8}$ inches in length of staple.

Twist per inch of single yarn, 33.8.
Twist per inch of ply yarn, 18.5.
Construction of cloth, 68 ends by 68 picks.
Strength of caustic, 64 degrees Twaddle.

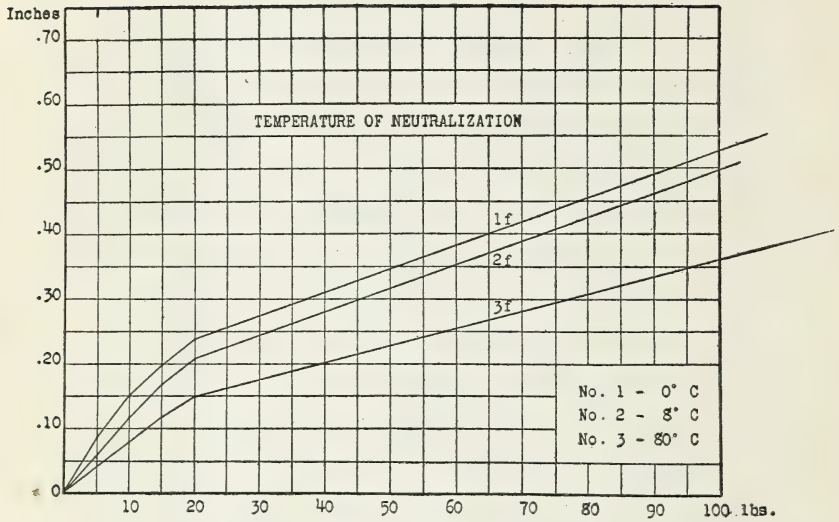

FIG. 11.—Elasticity curves showing the effect of different temperatures of the neutralizing solution used during the mercerization process. Plain-weave cloth made from 3/80's gray yarn spun from American Egyptian cotton of grade No. 1 (fancy), 1⅝ inches in length of staple.

Twist per inch of single yarn, 33.80.
Twist per inch of ply yarn, 18.5.
Construction of cloth, 68 ends by 68 picks.
Strength of caustic, 64 degrees Twaddle.

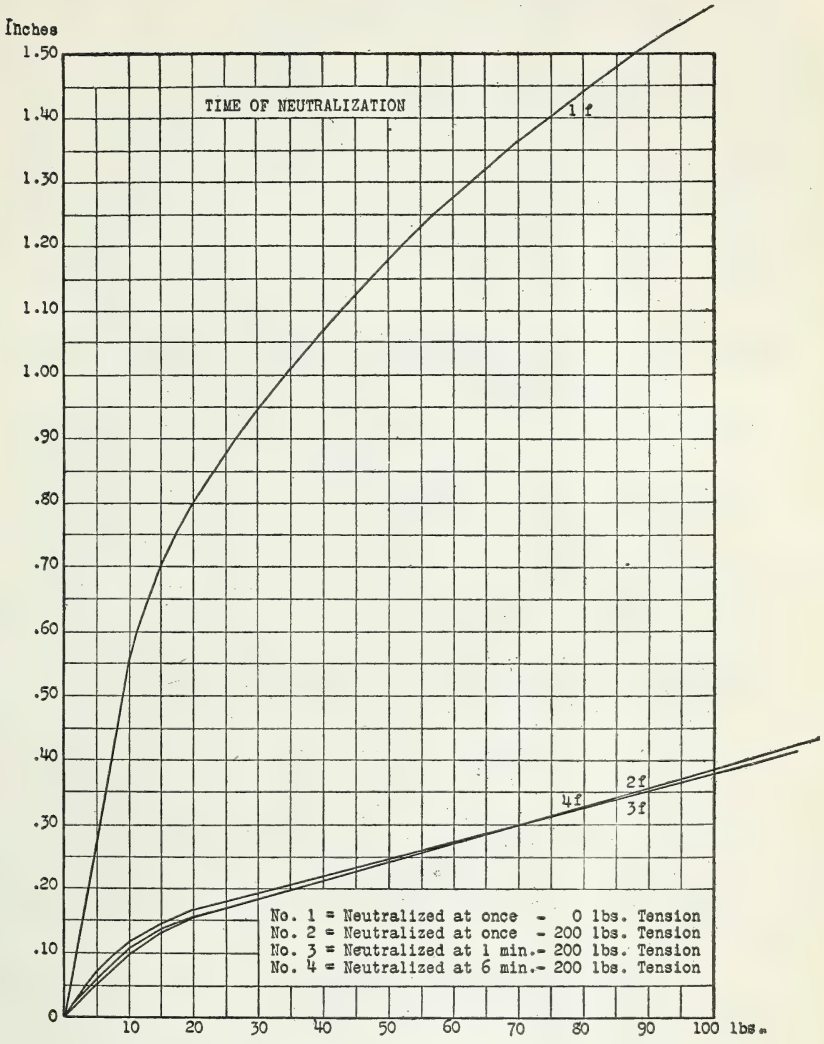

FIG. 12.—Elasticity curves showing the effect of neutralizing for different lengths of time during the mercerizing process. Plain-weave cloth made of 3/80's gray yarn spun from American Egyptian cotton of grade No. 1 (fancy), 1⅝ inches in length of staple.

Twist per inch of single yarn, 33.8.
Twist per inch of ply yarn, 18.5.
Construction of cloth, 68 ends by 68 picks.
Strength of caustic, 64 degrees Twaddle.

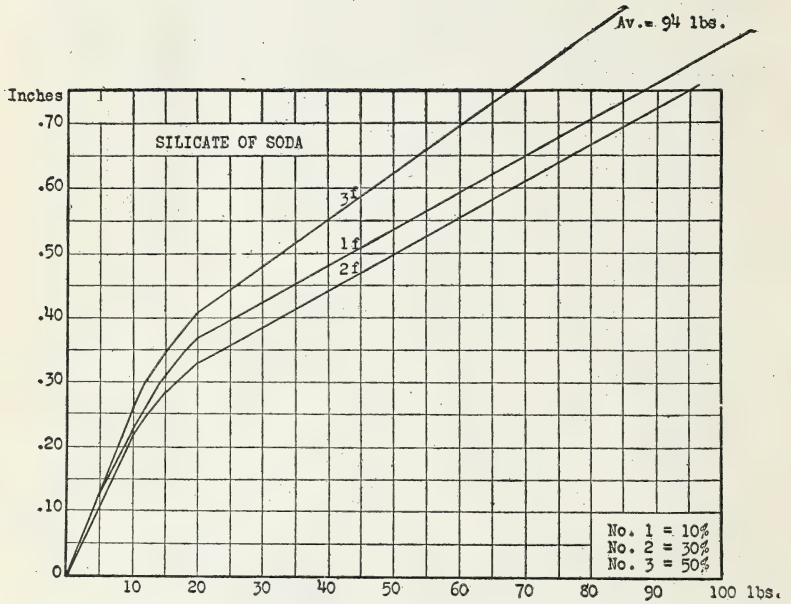

FIG. 13.—Elasticity curves showing the effect of additions of silicate of soda to the caustic bath. Plain-weave cloth made of 3/80's gray yarn spun from American Egyptian cotton of grade No. 1 (fancy), 1⅝ inches in length of staple.

twist per inch of single yarn, 33.8.
Twist per inch of ply yarn, 18.5.
Construction of cloth, 68 ends by 68 picks.
Strength of caustic, 64 degrees Twaddle.

However, as the above conditions could not be reproduced in practice, the following were used as a standard in the laboratory tests:

(*a*) Sixty-four degree Twaddle solution of caustic soda.
(*b*) Two hundred pounds tension.
(*c*) Twenty-five degrees Centigrade wash waters for neutralizing.
(*d*) One minute treatment with caustic soda solution before neutralizing.
(*e*) No chemicals added to the caustic bath.

Application of the conclusions drawn from the laboratory tests was then made by mercerizing piece goods on a commercial scale in a finishing plant where conditions were nearly the same as those adopted as a standard in the laboratory tests. The conditions that actually prevailed were as follows:

(*a*) Fifty to sixty degree Twaddle solution of caustic soda.
(*b*) Highest tension possible in machine without pulling cloth out of tenter clips.
(*c*) Wash water 190° to 40° F.
(*d*) No additions to the caustic liquor.
(*e*) Goods run directly from bale through caustic.
(*f*) Goods were mangled (a) through water, (b) through ½ per cent starch solution, and dried on tenter frames.

The cloths tested were the special twist cloths represented by samples Nos. 8, 9, 11, 12, 13, and 14, as given in Table 12. These results are shown graphically in figures 14 and 15.

From figures 14 and 15 the effect of tentering, starching, yarn mercerization, and piece mercerization can readily be seen and may be stated as follows:

(*a*) Tentering does not materially alter the stretch-stress qualities of the fabric.
(*b*) Starching slightly increases the breaking strength, although it is undesirable in airplane cloth, as it reduces the porosity and thus prevents good "doping."
(*c*) Yarn mercerization did not materially affect the stretch-stress qualities of this particular cloth.
(*d*) Piece mercerization decreased the stretch materially (approximately one-eighth of an inch in the 8-inch sample tested).

All of the finished fabrics were clear and bright in appearance and of good, firm feel, especially the piece-mercerized fabrics. The original piece-mercerized fabric, as shown in Table 10 or figure 15, gave the stretch in the direction of the warp considerably less than that in the direction of the filling. However, a second piece was mercerized to remedy this condition, with the result that the stretch-stress qualities were practically equalized, thus indicating that these qualities were fully controllable in the piece-mercerization process.

Having investigated the various physical properties of the above cloths in the usual manner, tests were made to determine the effect of continual stress upon these fabrics, so as to produce a condition

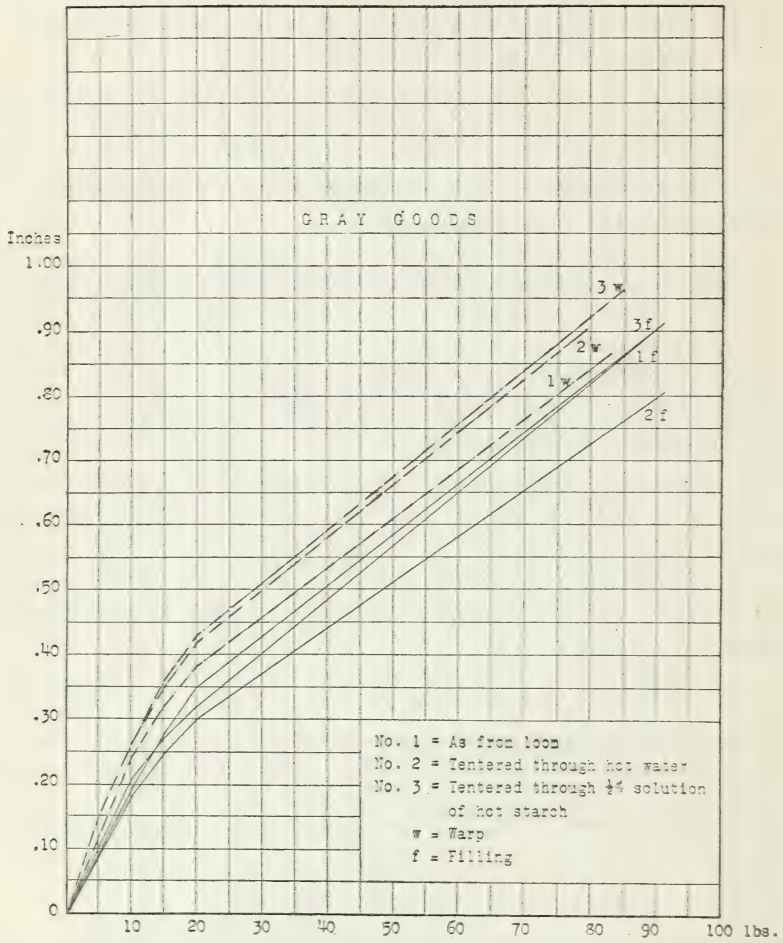

FIG. 14.—Elasticity curves showing the effect of tentering through hot water and 0.5 per cent solution of hot starch. Plain-weave cloth made of 3/80's gray yarn spun from American Egyptian cotton of grade No. 1 (fancy), 1⅝ inches in length of staple.

Twist per inch of single yarn, 33.8.
Twist per inch of ply yarn, 18.5.
Construction of cloth, 68 ends by 68 picks.

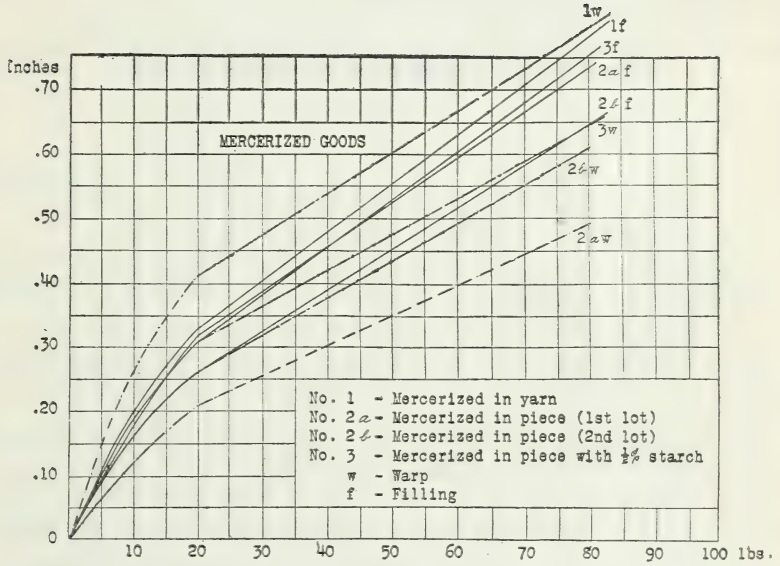

FIG. 15.—Elasticity curves showing the effect of yarn mercerizing and piece mercerizing with and without 0.5 per cent of starch. Plain-weave cloth made of yarn spun from American Egyptian cotton of grade No. 1 (fancy), 1⅝ inches in length of staple.

Twist per inch of single yarn, 33.8.
Twist per inch of ply yarn, 18.5.
Construction of cloth, 68 ends by 68 picks.
Strength of caustic, 64 degrees Twaddle.

that to a certain extent prevails during the flight of the airplane. These stresses were produced upon test samples 1 inch by 12 inches (8 inches between the jaws) by disengaging the weight pawl and loading the machine by hand at the rate of approximately 1 inch per minute. Stresses of 90, 80, and 70 per cent of the original breaking strength of the cloth were produced and the sample allowed to remain in the machine until it broke from this continual load or until a reasonable time had passed in which it was certain that the cloth could be stressed indefinitely without breaking. The results of these tests are shown below:

TABLE 14.—*Effect of continual stresses on 68 by 68 plain weave fabrics made from fancy Pima 1⅝ inch American Egyptian cotton.*

Sample No.	Fabric.	Time of stressing at—		
		70 per cent load.	80 per cent load.	90 per cent load.
		H. m. s.	*H. m. s.*	*H. m. s.*
1	Standard specifications	18 0 0	1 42 30	0 0 10 (Broke.)
2	Special twist yarn, mercerized [1]	24 30 0	1 23 0 (Broke.)	0 0 0 (Broke.)
3	Special twist, mercerized in the piece	68 45 0	3 17 0 (Broke.)	0 1 0 (Broke.)
4	Special twist, mercerized in the piece and ½ per cent starch	65 30 4	3 0 0 (Broke.	0 1 30 (Broke.)

[1] The twist in the yarn of which this cloth is made was that obtained from using a twist multiple of 3.83 in the singles and 3.63 in the ply.

The above table is supplemented by figure 16, and in connection therewith the following conclusions are drawn: None of the fabrics were reliable when subjected to 90 per cent of the load in the manner described; for 80 per cent they were reliable for only a few hours; and for 70 per cent they were reliable for an indefinite length of time. These results show that the piece-mercerized sample was the best of the fabrics tested.

Microscopic examination was made of the piece-mercerized fabric in comparison with the corresponding gray cloth to determine what effect mercerization had upon the construction of the cloth. This investigation showed that the number of ends per inch in the warp and filling remained constant. The diameter of the threads had been decreased, but despite this fact the dimensions of the interstices decreased because of the flattening of the yarns in the cloth by the heavy roller of the mercerizing machine. The results of these tests are shown in Table 15.

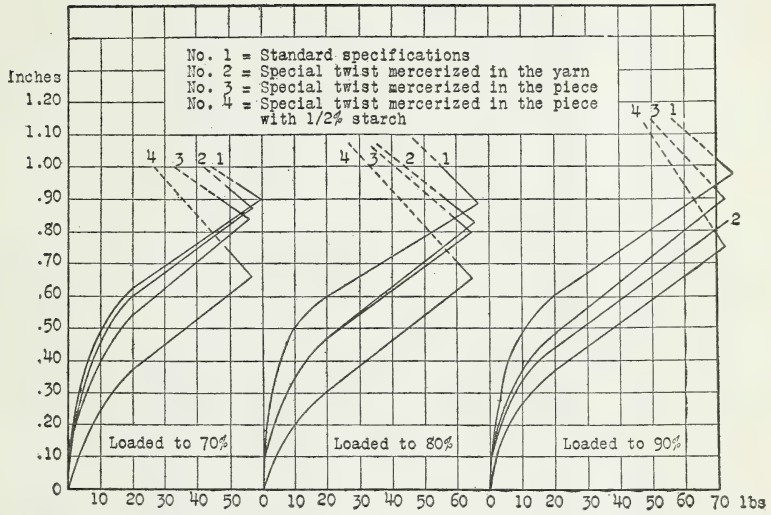

FIG. 16.—Elasticity curves showing the effect of loading different test samples of mercerized cloth by hand to different loads and allowing the cloth to be subjected to continual load by disengaging the weight pawl. Plain-weave cloth mercerized in the yarn and mercerized in the piece made of 3/80's yarn spun from American Egyptian cotton of grade No. 1 (fancy), 1⅝ inches in length of staple.

	Standard specifications.	Special twist.
Twist per inch of single yarn	36–40	33. 80
Twist per inch of ply yarn	18–20	18. 5

Construction of cloth, 68 ends by 68 picks.
Strength of caustic, 64 degrees Twaddle.

TABLE 15.—*Effects of mercerization upon construction of cloth.*

	Diameter of yarn.		Dimensions of interstices.		Variations in diameter of yarn.[1]	
	Warp.	Filling.	Warp.	Filling.	Warp.	Filling.
	Inches.	*Inches.*	*Inches.*	*Inches.*		
Gray	0.008393	0.008718	0.005059	0.004500	11–18	12–19
Piece mercerized	.007873	.008491	.004400	.004330	12–17	11–17

[1] The figures in this column may be converted into inches by multiplying by 0.03937 and dividing the result by 70.

Having determined the various properties of the fabric composed of 3/80's yarn, further tests were made to determine if the ideal conditions of equal stretch in the warp and filling could be obtained for the 2/60's fabric through piece mercerization. Sea Island cotton was used for this experiment and cloth made according to the Signal Corps Specifications 16,004–A was tested. This cloth was sent to two finishing plants for mercerizing in the piece, without direct supervision by the personnel of the Bureau of Markets, so as to furnish an indication of what might be expected of cloth of this description under normal commercial conditions of mercerization. The results corroborated the conclusions drawn from the tests on the 3/80's cloth. These results are shown by Table 11 and also by Figure 17.

DOPING.

In order to give the airplane wing the smoothness, tautness, and rigidity necessary to minimize the wind resistance, a solution commonly termed "dope" is applied. Doping usually consists of the application of several coats of either cellulose acetate or cellulose nitrate, or both, and is followed by a single coat of varnish to make the fabric waterproof.

A representative of the Bureau of Markets visited an airplane factory in order to study the methods of application of the dope to fabrics. Several conferences were held with the experts of the factory and an analysis was made of a doped sample. As a result the following method was adopted for comparative tests on the doped fabrics made from the different varieties of cotton and also for comparative tests to determine the best weave. It was thought that these conditions approached as nearly as possible those that prevail in airplane factories.

(*a*) Four coats of dope and one coat of varnish, weighing approximately 60 per cent of the fabric, were used.

(*b*) Nitrate dope used exclusively.

(*c*) Fabric stretched under 5 pounds floating load.

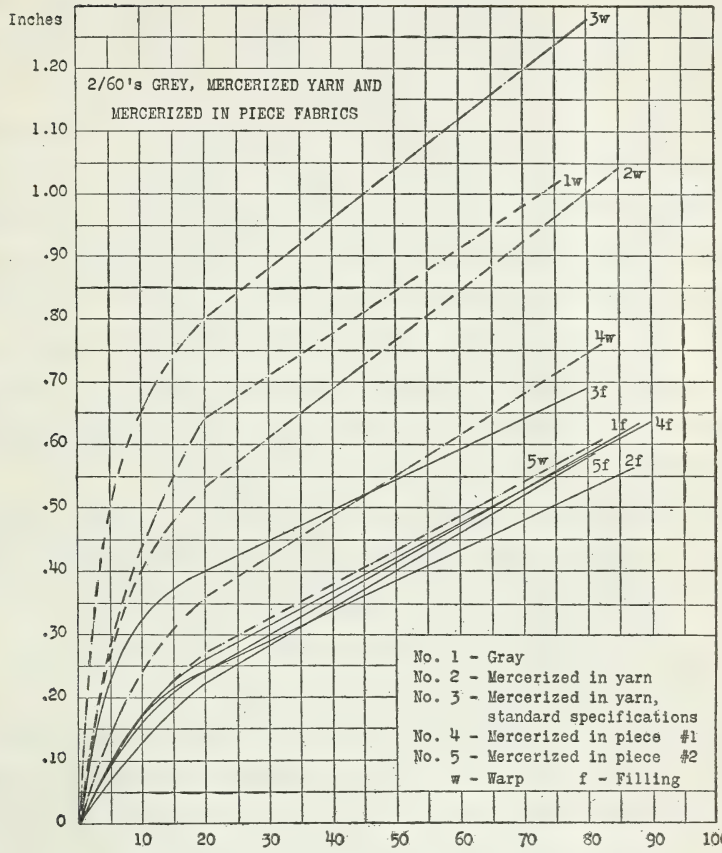

FIG. 17.—Elasticity curves showing the effect of yarn mercerizing and piece mercerizing upon plain-weave cloth made of 2/60's yarn spun from Sea Island cotton of grade represented by a mixture of one bale of No. 1, two bales No. 2, and two bales of No. 3, all $1\frac{7}{16}$ inches in length of staple.

	Standard specifications.	Twist of Nos. 1, 2, 4, 5.
Twist per inch of single yarn	28–34	30. 5
Twist per inch of ply yarn	16	21. 5

Construction of cloth, 80 ends by 80 picks.
Strength of caustic, 64 degrees Twaddle.

For the comparative tests, fabrics made from Sakellaridis Egyptian, Sea Island, and American Egyptian cottons according to the Signal Corps specifications (*a*) and (*b*) were doped in the manner described above. These tests indicated that the lowest stretch was obtained with cloth made from the Sakellaridis Egyptian cotton, and the greatest with cloth composed of the American Egyptian, although there was very little difference between the sea island and the American Egyptian.

For the tests to determine the best weave, cloths made of similar 3/80's mercerized yarn were used and the following were studied: Plain weave made according to Specifications 16,005–A; 2/2 basket weave of 68 ends by 68 picks per inch; and 2/2 twill of 68 ends by 68 picks per inch. Accepting as the proper basis of judgment that the highest tensile strength combined with the least stretch is best for airplane fabrics, and without considering the tendency of the fabric to draw when stretched on the panel of the airplane frame, these tests indicated that the basket weave was the best for the purpose. In general, they confirmed the results previously obtained upon the fabrics before doping, and thus show that the stretch-stress relations of the fabric are changed only in quantity by doping.

Having determined the best commercial variety of cotton and best weave for airplane fabrics, efforts were then turned toward determining the relation of the various contributing agents to the final result. The following points were studied:

(*a*) Influence of the percentage of dope applied.
(*b*) Influence of the doping material.
(*c*) Influence of the stress conditions before doping.

From these investigations it was determined that increasing the percentage of dope beyond 117 per cent did not improve the stretch-stress qualities of the doped fabric, but increasing the per cent of dope to this amount had decreased the stretch considerably, although the weight of the fabric had been thereby greatly increased (compare Figs. 20 and 21); that the nitrate dope produced slightly better results than the acetate dope, together with improved properties from varnishing (Fig. 21); and that stretching the fabric before doping reduced materially the stretch component of the doped fabric (Fig. 22).

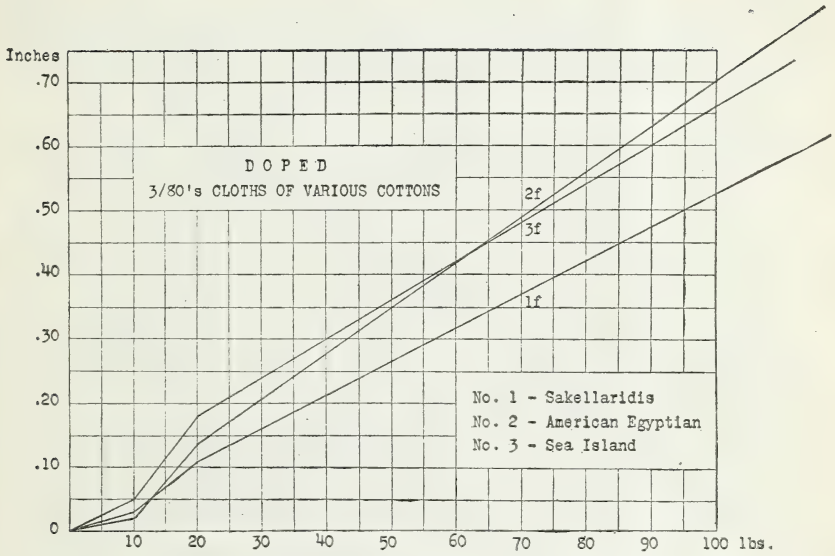

FIG. 18.—Elasticity curves showing the effect of dope upon plain-weave cloth made of 3/80's mercerized yarn spun from the different varieties of cotton.

Twist per inch of single yarn, 35.6.
Twist per inch of ply yarn, 20.6.
Construction of cloth, 68 ends by 68 picks.
Strength of caustic, 64 degrees Twaddle.
Percentage of dope, 60.

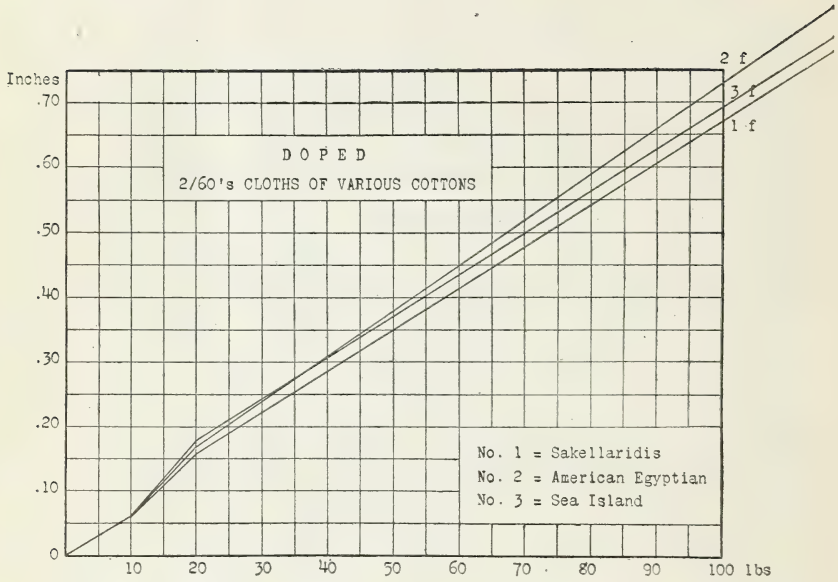

FIG. 19.—Elasticity curves showing the effect of dope upon plain-weave cloth made of 2/60's mercerized yarn spun from the different varieties of cotton.

Twist per inch of single yarn, 30.5.
Twist per inch of ply yarn, 21.5.
Construction of cloth, 80 ends by 80 picks.
Strength of caustic, 64 degrees Twaddle.
Percentage of "dope," 60.

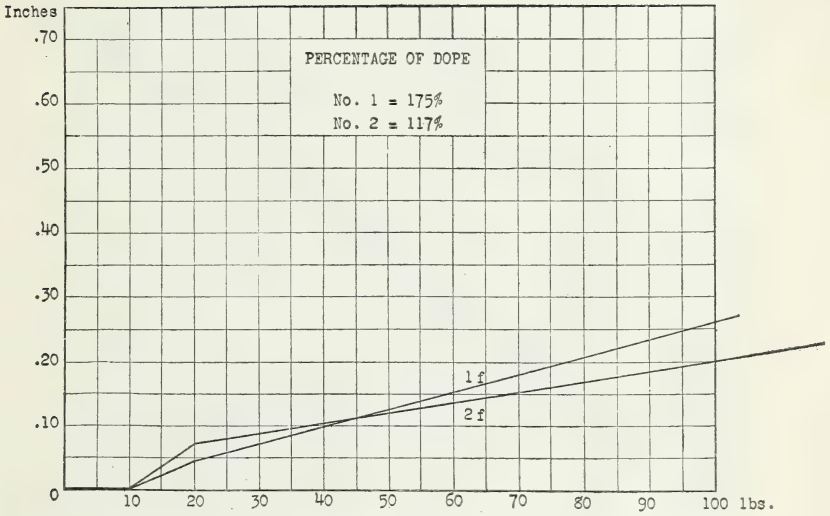

FIG. 20.—Elasticity curves showing the effect of different amounts of dope upon plain-weave cloth made from 3/80's mercerized yarn spun from American Egyptian cotton of grade No. 1 (fancy), 1⅝ inches in length of staple.

Twist per inch of single yarn, 35.6.
Twist per inch of ply yarn, 20.6.
Construction of cloth, 68 ends by 68 picks.
Strength of caustic, 64 degrees Twaddle.

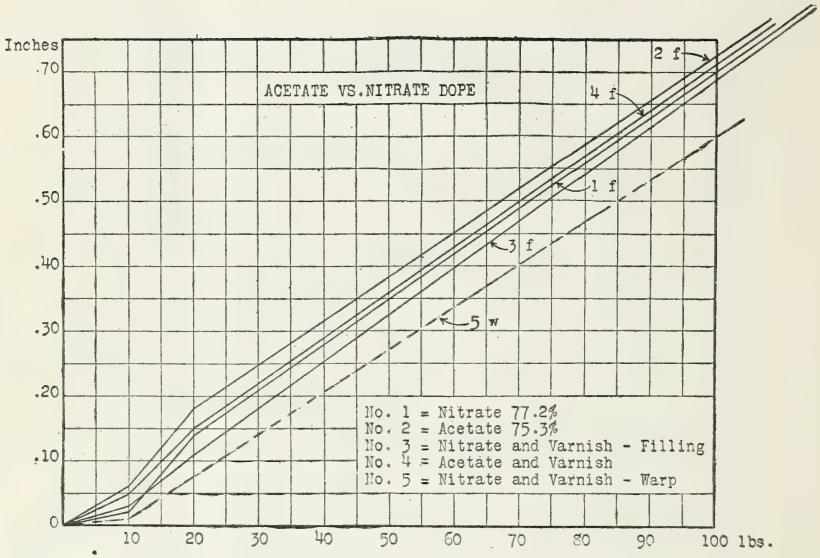

FIG. 21.—Elasticity curves showing the effect of nitrate dope as compared with acetate dope. Plain-weave cloth made from 3/80's mercerized yarn spun from American Egyptian cotton of grade No. 1 (fancy), 1⅝ inches in length of staple.

Twist per inch of single yarn, 35.6.
Twist per inch of ply yarn, 20.6.
Construction of cloth, 68 ends by 68 picks.
Strength of caustic, 64 degrees Twaddle.

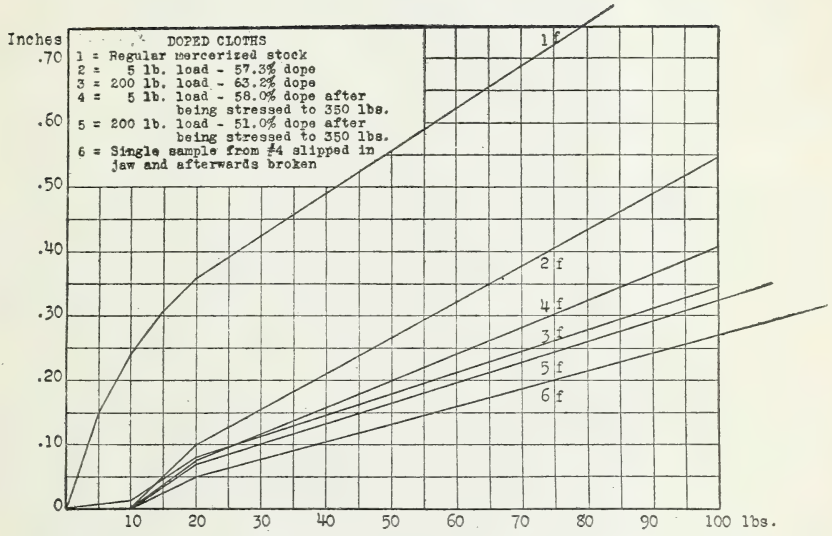

FIG. 22.—Elasticity curves showing the effect of doping under different tensions. Plain-weave cloth made of 3/80's mercerized yarn spun from American Egyptian cotton or grade No. 1 (fancy), 1§ inches in length of staple.

Twist per inch of single yarn, 35.6.
Twist per inch of ply yarn, 20.6.
Construction of cloth, 68 ends by 68 picks.
Strength of caustic, 64 degrees Twaddle.

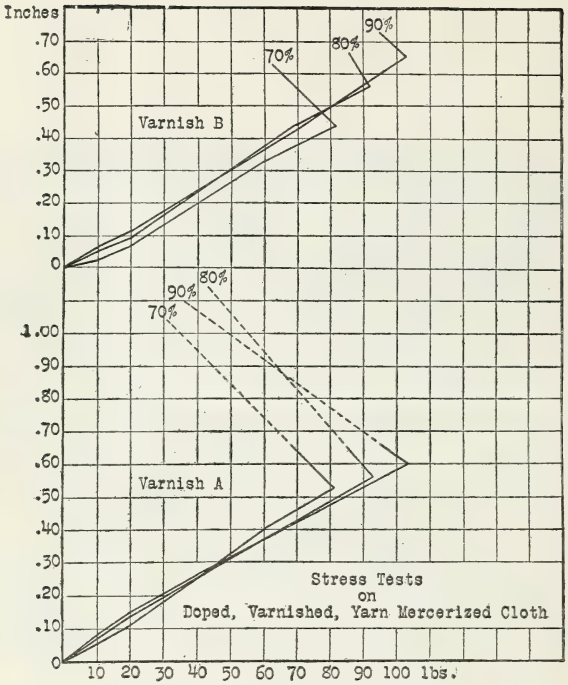

FIG. 23.—Elasticity curves showing the effect of loading different test samples of doped cloth by hand to different loads and allowing the cloth to be subjected to continual load by disengaging the weight pawl. Plain-weave cloth made of 3/80's mercerized yarn spun from American Egyptian cotton of grade No. 1 (fancy), 1⅝ inches in length of staple.

Twist per inch of single yarn, 35.6.
Twist per inch of ply yarn, 20.6.
Construction of cloth, 68 ends by 68 picks.
Strength of caustic, 64 degrees Twaddle.
Percentage of dope, 60.

Having applied the usual tests on the doped cloths, further investigations were made to determine the behavior of these cloths when subjected to continual load as was done in the case of the mercerized fabrics. Yarn mercerized cloth of Specifications 16,005–A, made from American Egyptian cotton, was used for this test, the results of which are given below:

TABLE 15.—*Behavior of doped cloths under continual leading.*

	Time of stressing at—		
	70 per cent.	80 per cent.	90 per cent.
	H. m. s.	*H. m. s.*	*H. m. s.*
Varnish A	12 0 0	0 10 0 (Broke.)	0 2 30 (Broke.)
Varnish B	24 0 0	0 31 0 (Broke.)	0 3 40 (Broke.)

The above table is supplemented by figure 23. The conclusions drawn from these results are that the fabrics are unreliable when subjected to continual stress that is greater than 70 per cent of the breaking strength determined by the method described in the Signal Corps Specifications.

SUMMARY.

These tests showed no wide differences in the amount of waste discarded by the three varieties of cotton; the Pima American Egyptian cotton showed a waste percentage of 29.09; Sea Island, 26.70; and high-grade Sakellaridis-Egyptian, 27.07.

Sakellaridis-Egyptian cotton gave the strongest yarn and cloth, a general average of all of the results showing a superiority of about 12 per cent over the Sea Island and the American-Egyptian.

It was found that the twist recommended by the Signal Corps Specifications for 80's and 3/80's yarns was excessive, the best results being obtained by a combination of twist multiples 3.83 in the singles with 3.63 in the ply.

Of the several weaves tested, the plain weave was found to be the most practical.

Piece mercerization was found to be superior to yarn mercerization because it allowed increased quantity and uniformity of production while decreasing its cost; at the same time it conserved labor, material, and transportation facilities. It also tended to reduce and equalize the stretch in the warp and filling without materially changing its strength per unit of weight.

Doping changed the stretch-stress qualities of the cloth in quantity only. Nitrate dope gave slightly superior physical properties to the

cloth than those given by acetate dope. Increasing the percentage of dope beyond 117 per cent did not improve the stretch-stress qualities of the cloth.

Tests of cloth made by subjecting it to continual stresses in comparison with the usual method as described in the Signal Corps Specifications showed that the former method produced results approximately 30 per cent weaker than the latter.

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